

REMOTELY PILOTED VEHICLES FOR EXPERIMENTAL FLIGHT CONTROL TESTING

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A successful flight test and training campaign of the NASA Flying Controls Testbed was conducted at Naval Outlying Field, Webster Field, MD during 2008. Both the prop and jet-powered versions of the subscale, remotely piloted testbeds were used to test representative experimental flight controllers. These testbeds were developed by the Subsonic Fixed Wing Project's emphasis on new flight test techniques. The Subsonic Fixed Wing Project is under the Fundamental Aeronautics Program of NASA's Aeronautics Research Mission Directorate (ARMD). The purpose of these testbeds is to quickly and inexpensively evaluate advanced concepts and experimental flight controls, with applications to adaptive control, system identification, novel control effectors, correlation of subscale flight tests with wind tunnel results, and autonomous operations. Flight tests and operator training were conducted during four separate series of tests during April, May, June and August 2008. Experimental controllers were engaged and disengaged during fully autonomous flight in the designated test area. Flaps and landing gear were deployed by commands from the ground control station as unanticipated disturbances. The flight tests were performed NASA personnel with support from the Maritime Unmanned Development and Operations (MUDO) team of the Naval Air Warfare Center, Aircraft Division

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INTRODUCTION

The deployment of low-cost remotely piloted testbeds for advanced concept validation is one of the goals of NASA's Subsonic Fixed Wing Project, namely, "to enhance critical facility and testbed capabilities." The benefit of remotely- and auto-piloted testbeds is that they provide an enormous advantage over comparable piloted or optionally piloted vehicles in terms of size, speed, risk and cost. Consequently, advances in flight control research and technology using pro-

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gressively greater levels of autonomy can be pursued with limited resources. Two such testbeds currently supported by Subsonic Fixed Wing are the NASA Flying Controls Testbed (FLiC) and the more capable jet powered version, (J-FLiC). FLiC was initiated under NASA Langley's Creativity and Innovation program in 2002, and after several years and hundreds of developmental flights, it evolved into J-FLiC in 2006. Both testbeds are engaged in current flight test campaigns being conducted at Naval Air Station Patuxent River, Webster Outlying Field, St Inigoes, MD, with support from the Maritime Unmanned Development and Operations (MUDO) team of the Naval Air Warfare Center, Aircraft Division (NAWCAD). The sequel will provide some brief background, describe the results of the 2008 test campaign and planned work for the upcoming year.

FLiC

The Flying Controls Testbed (FLiC) proposed to conceive, develop, implement, and flight test highly experimental and perhaps even controversial flight control technologies in a relatively low cost and low risk platform. Early efforts in the program focused on developing an inexpensive, small, relatively slow test platform controlled by a commercially available autopilot, Micropilot® 2028, capable of stabilizing, navigating, and recording flight data. This initial version of the FLiC was based on the AN/FQM-117B, a surplus Army target drone provided by the Applied Aviation Technology Directorate at Fort Eustis, Virginia. FLiC, shown in Figure 1, served as the experimental testbed for self-organizing map (SOM) based multiple-model controllers as well as a training and development platform for both remotely-piloted and auto-piloted flight operations.^{1, 2}

³ On June 27th, 2005, FLiC performed a fully autonomous flight test demo at the Association for Unmanned Systems International (AUVSI) UAV Demo 2005, held at Naval Outlying Field, Webster Field, MD. Several earlier papers document the development of FLiC in detail.^{4, 5 6}



Figure 1. FLiC with 16 aileron segments.

J-FLiC

J-FLiC essentially uses the same avionics, i.e. autopilot, radio modems, radio control transmitter/receiver and UAV safety switch, as its prop-version predecessor. The fundamental difference is in the airframe, engine, and autopilot control gains and settings. The airframe is the commercially available Bob Violett Models (BVM) KingCat. It is well behaved at both high and low

speeds, recovers from spins and stalls predictably. It is highly visible, particularly in the Langley Research Center orange and black paint scheme shown in Figure 2. Powered by the JetCat P-120SX turbine engine producing 30 pounds of thrust, takeoff distances are on the order of 300 feet, climb rates are in excess of 2000 fpm and sustained speeds of 200 mph are easily achieved in level flight. J-FLiC is shown on the runway at Webster Field in Figure 2. J-FLiC has completed 150 flights as of June 2009, with approximately two-thirds (95) of those flights engaging autopilot control during some segment of the flight. Similar to FLiC, several papers report the development of J-FLiC in detail.^{7,8}



Figure 2. J-FLiC on the runway at Webster Field.

J-FLiC also performed an autonomous flight demo, this one at the 4th Biennial AUVSI UAV Demo 2007 held at Webster Field, MD on August 6th, 2007. J-FLiC flawlessly executed both the manually and auto-piloted segments of the scripted flight plan, with a manually piloted takeoff and climbout to 800 feet at 80 knots, and autopilot engagement at altitude. The autopilot executed the pre-programmed flight plan, essentially racetrack patterns at decreasing altitude and increasing speed during the segment down the runway in front of the spectators. The initial pass was at 750 feet altitude with an airspeed of 90 knots, with successive passes made at 50 foot decrements in altitude. The final pass was at 500 feet altitude at 160 knots. Altitude was maintained within 25 feet of target and the required lateral displacement from the spectators was maintained at all times, as executed during the rehearsals held under intense scrutiny during the two previous days. Additionally, the autopiloted segment of the flight included a final cooldown circuit at 80 knots. The autopilot was disengaged for entry into the landing pattern. A gear pass and subsequent full stop landing were performed under manual control.

FLIGHT TESTS 2008

Initial FLiC and J-FLiC training flights at Webster Field, April 7-10, 2008

During the week of April 7th, 2008, the initial series of flights were completed on both prop and jet-powered remotely piloted vehicles being developed under the Subsonic Fixed Wing (SFW) Program's Experimental Capabilities discipline. These flights were conducted at Naval

Outlying Field, Webster Field, MD with the support of the Naval Air Warfare Center, Aircraft Division's Maritime Unmanned Development and Operations (MUDO) Team. The weather was generally uncooperative during the week but several intervals provided the opportunity to complete the initial training flights.

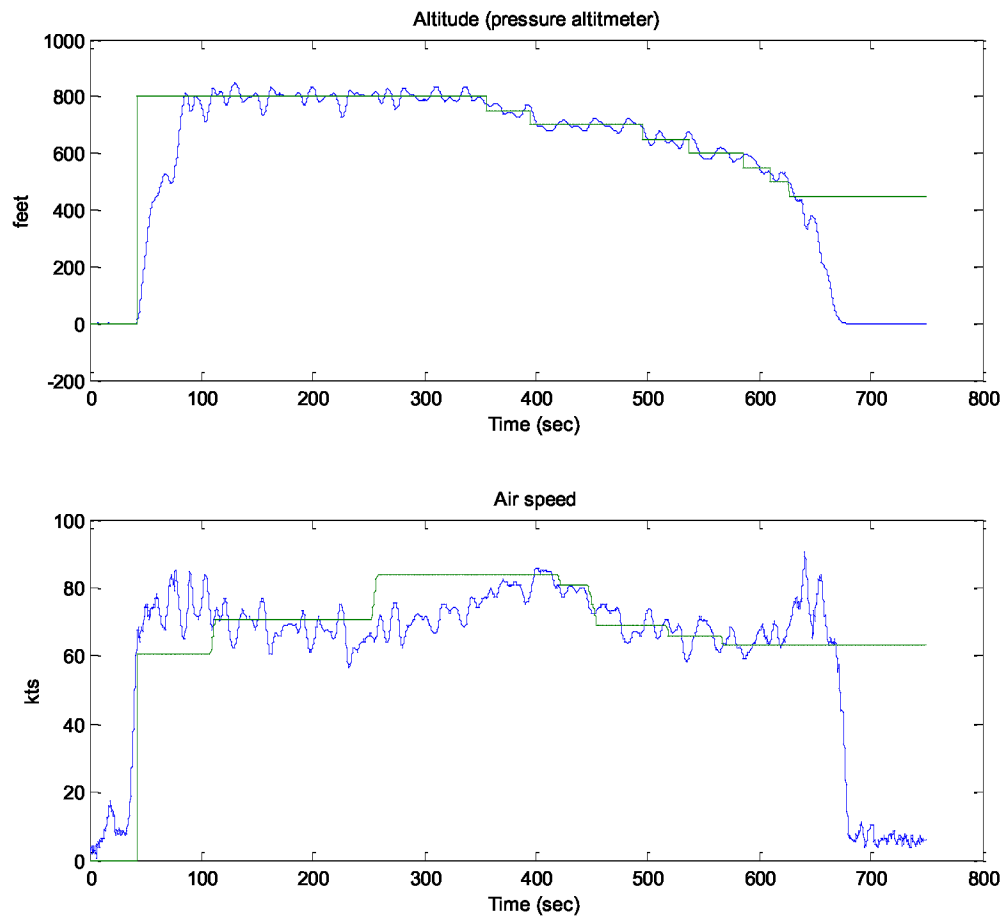


Figure 4. Altitude and Airspeed during Flight Card number 8, April 10, 2008.

Flight cards 1-8 were completed, covering pilot and ground crew training on manual and autopiloted operations including nominal and emergency conditions on both the prop and jet powered test platforms. Typical emergency operations training included simulated engine out and no-flap approaches in manual mode and return to home procedures in autopiloted mode. All flights were conducted in accordance with the established test and support plans. This initial round of training flights set the stage for flight tests of the representative experimental controllers, which were to be the focus of the next series of flights. Flight card eight exercised the autopiloted return-to-home capability, where the ground control station (GCS) operator engages the return to home flight path, simulating what would occur if either of the two command links were lost for the prescribed interval. After reaching the home or return-to-base (RTB) point the desired or target altitude was reduced by the GCS operator as well. At approximately 450 feet, the autopilot was

disengaged and a manual landing was performed. Figure 4 shows the altitude and airspeed for the flight and Figure 5 shows the GCS display for that flight card..

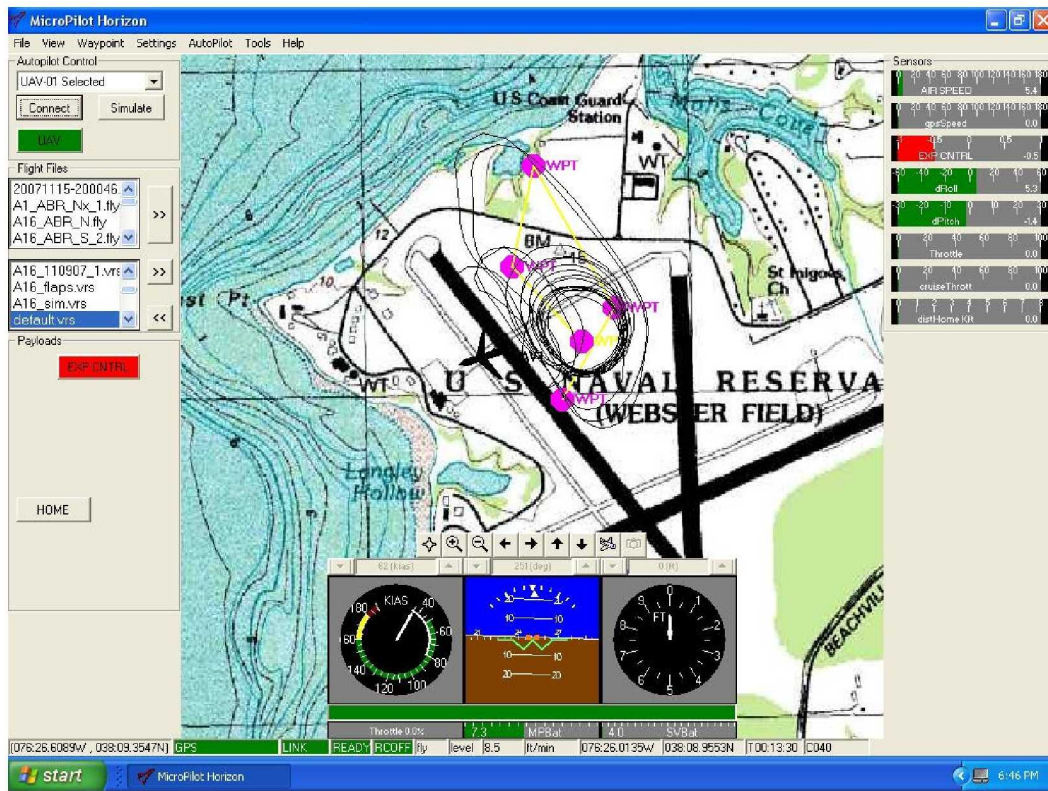


Figure 5. GCS display for Flight Card number 8 , April 10, 2008.

May 21-22nd 2008

The jet-powered version of the Flying Controls testbed (J-FLiC) successfully completed a second round of flight tests at the Naval Outlying Field (NOLF) Webster Field, MD. The emphasis on this round of flight tests was to demonstrate the ability of J-FLiC to engage and disengage an experimental flight controller while in autopiloted, autonomous flight. Ten flights were successfully executed over a two day period, May 21-22, covering eight flight cards. Completed cards included emergency procedures for both manual (simulated engine out) and autopiloted flight (Return to HOME/lost link) from a new operating position on runway 8/26. This location provided access to the test area designated for experimental controller testing. Airspeed-to-throttle table lookups were verified with steady autopiloted flight at 800 feet at airspeeds between 60 and 120 kts. Step disturbances to airspeed were induced with deployment of landing gear and full landing flaps at speeds between 80 and 100 kts. The representative experimental controller was engaged from the ground control station (GCS) in various modes providing fixed incremental corrections as directed from the GCS, proportional and integral corrections from airspeed error feedback, or a combination of both.

Figure 6 displays the airspeed and throttle command during one of the initial tests. As the airspeed settles near 100 knots, the landing gear is lowered, producing a step disturbance of approximately 20 knots. At approximately $t = 120$ sec, the representative experimental controller, here

just a proportional-integral (PI) controller with both absolute and integral component limiting, is engaged and reduces , but does not eliminate the airspeed error due to the conservative limiting employed during these initial tests. At time $t = 225s$, full flaps are deployed, inducing an additional 10 kt decrement which is only minimally compensated. At time $t = 325s$, both gear and flaps are raised, producing a fairly abrupt 30 kt increase in airspeed, which is quickly regulated back to 100 kts. Figure 7 shows the GCS display during the initial experimental controller test, flight card number 16.

Additionally during that week, live (all systems on with engines running) Electromagnetic Compatibility (EMC) tests were performed between both prop and jet versions (FLiC/J-FLiC) and the Navy's Fire Scout unmanned helicopter. Collectively, all these tests demonstrate the suitability of the testbed for truly experimental controllers, the operational capability to test the controllers, and the availability of flight test data for adaptive controller development.

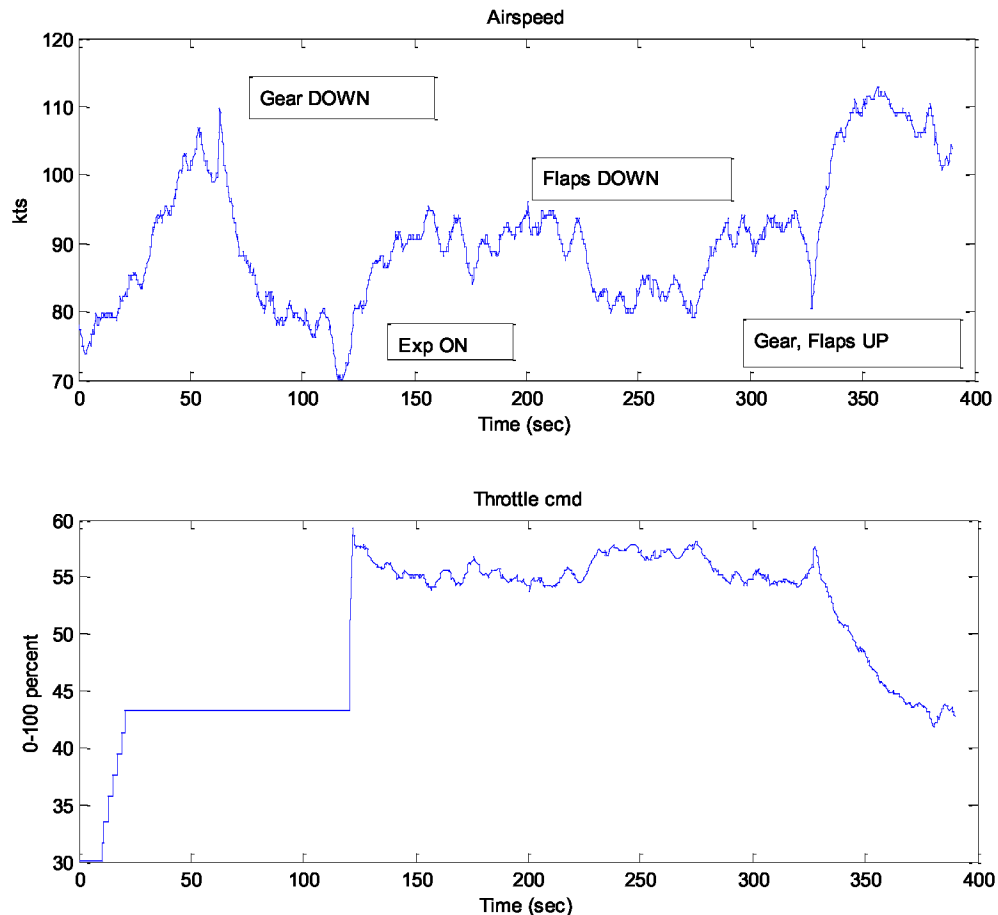


Figure 6. Airspeed and Throttle during Flight Card number 16, May 22, 2008.

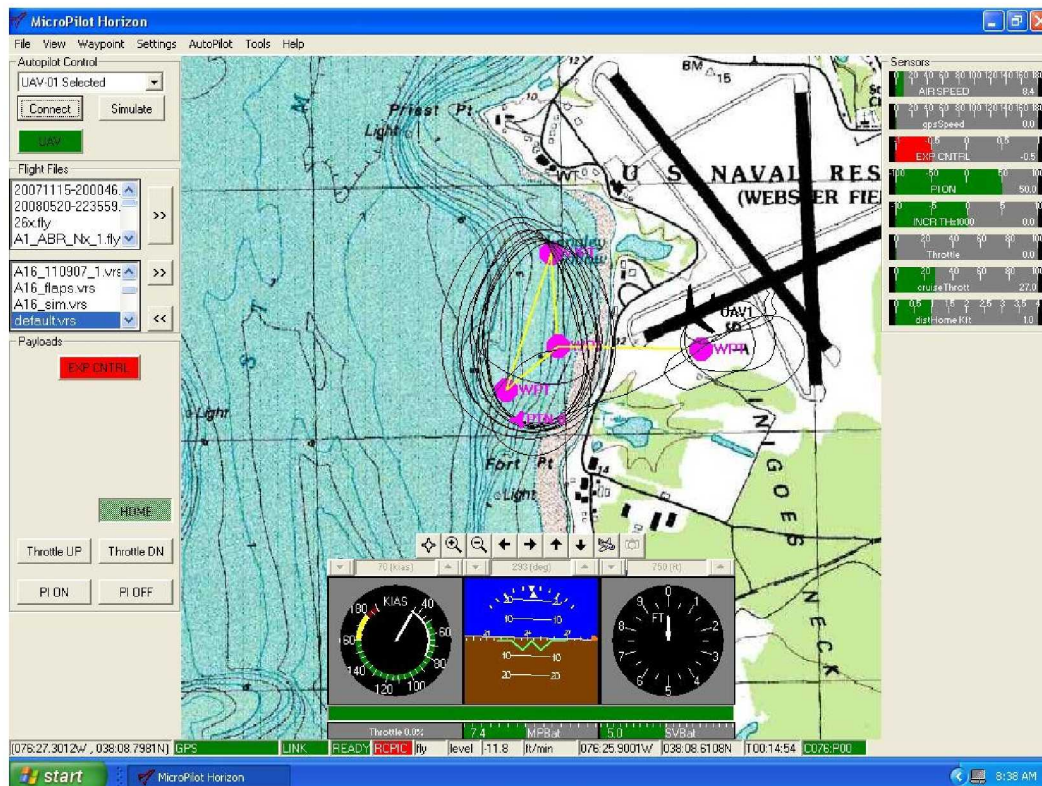


Figure 7. GCS display for Flight Card number 16 , May 22, 2008.

June 24-26th, 2008

Both prop and jet-powered versions of the FLYing Controls testbed (FLiC / J-FLiC) successfully completed another round of flight tests at the Naval Outlying Field (NOLF) Webster Field, MD. Twenty-five flight cards were completed over a three day period from June 24th through June 26th, with thirteen flights on the jet and a dozen on the prop. The flight tests were performed by NASA Langley personnel from the Electronic Systems with test plan and Mission Commander support from the Maritime Unmanned Development and Operations (MUDO) team, Naval Air Warfare Center, Aircraft Division (NAWCAD).

This round of flight tests included stall recovery, manual and autopiloted emergency procedures, and experimental controller engagement on the prop powered testbed as well as the jet version. The earlier round of tests had focused on the jet only. Data from earlier tests used to update the table lookups for airspeed control was verified and additional flights were conducted at speeds up to 140 kts for additional autopilot speed control validation on the jet. Airspeed and altitude for this flight card are shown in Figure 8, with the corresponding GCS display in Figure 9.

Additionally, Electromagnetic Compatibility (EMC) tests were performed between FLiC/J-FLiC and the NAWCAD's Aerostar UAV. Simultaneous operation of both Aerostar and J-FLiC was performed, with coordination of the exclusive use airspace in R4005 coordinated by the Mission Commander and the airfield tower.

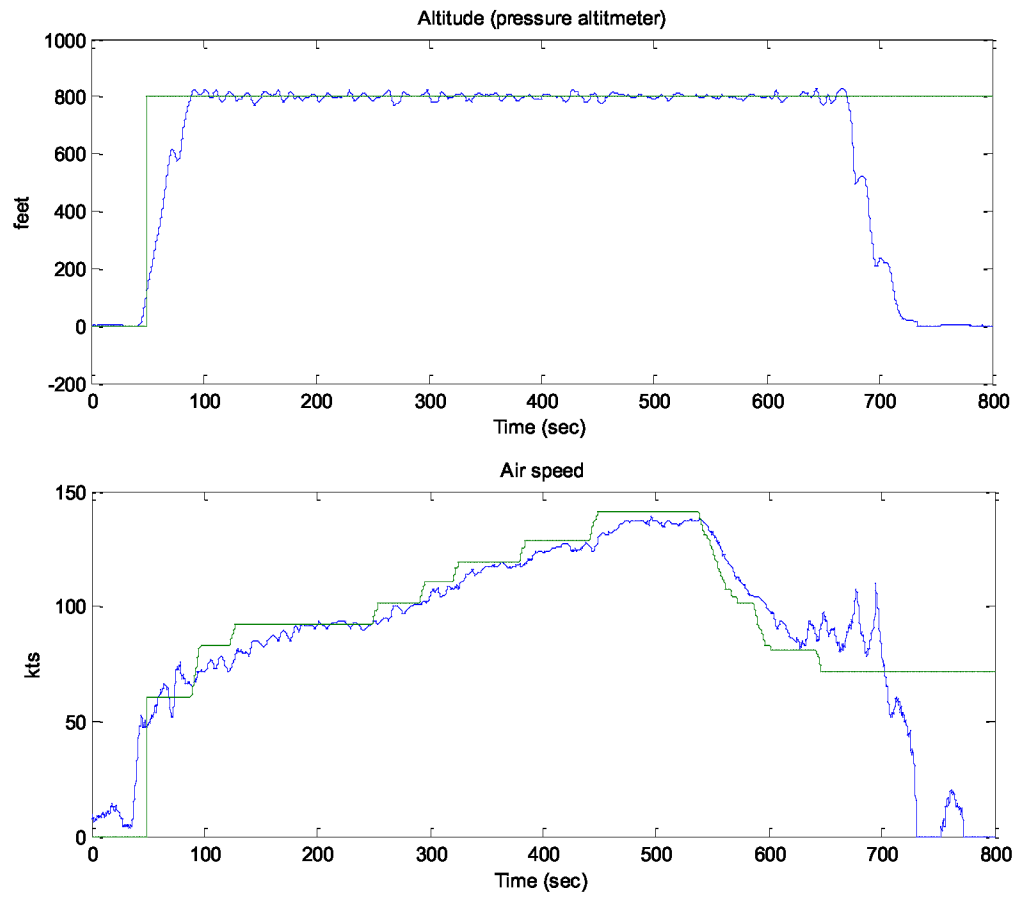


Figure 8. Airspeed and Throttle during Flight Card number 23 , June 25, 2008.

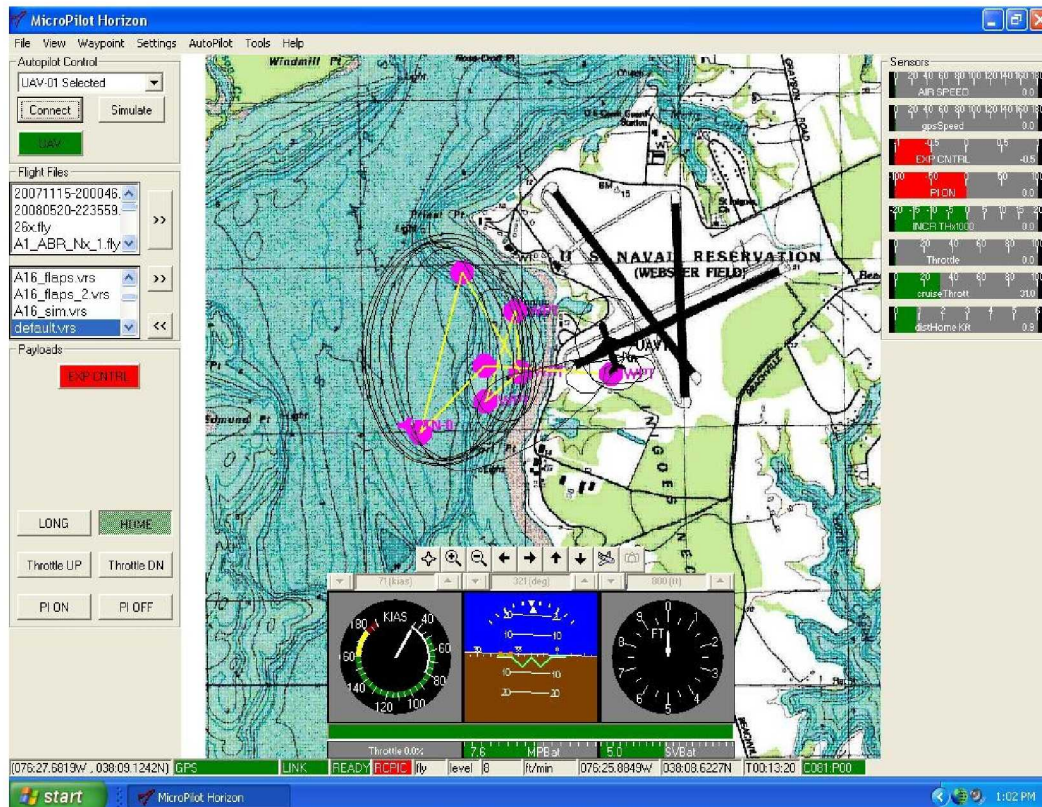


Figure 9. GCS display for Flight Card number 23 , June 25, 2008.

August 19th-21st, 2008

Twenty-five flight cards were completed over a three day period from August 19th through August 21st, with thirteen flights on the jet and nine on the prop. This round of flight tests expanded the autopiloted operational capability to include sustained descent and capture of successively lower altitudes down to 200 feet, landing approach, go around, and auto takeoff, all executed by ground control station commands. Autopiloted descents, landing approaches and go-arounds were performed by both FLiC (prop) and JFLiC (jet) on runways 8, 26 and 33. FLiC completed two successful auto-takeoffs, one on runway 8 and one on runway 26. JFLiC completed ground roll tests in preparation for auto-takeoff. Continued refinements to the experimental controller on the jet provided snappy compensation for representative, unscheduled (no feed-forward or apriori information) disturbances such as landing gear and flap deployment from 90 to 60 kts to within 5kts of target airspeed, shown in Figure 10, with corresponding GCS display of the flight path in Figure 11. A series of autopiloted descents and go-arounds on J-FLiC are depicted in Figures 12 and 13. Manual and autopiloted emergency procedures, as well as pilot proficiency training including sustained high speed circuits (140 kts) and touch and goes rounded out the campaign.

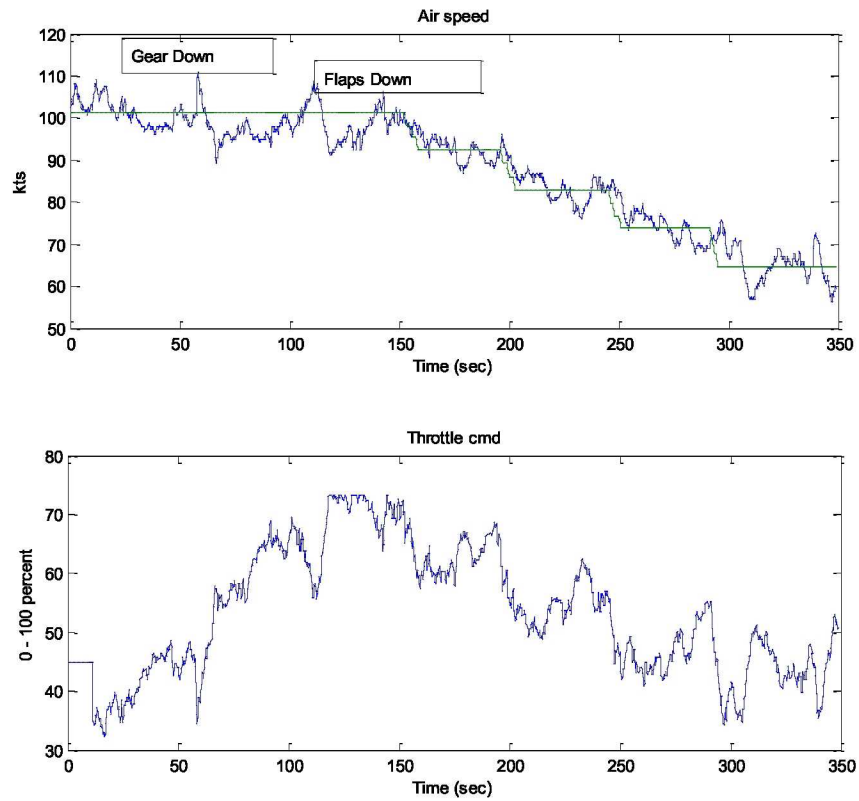


Figure 10. Airspeed and Throttle during Flight Card number 20 , Aug 20, 2008.

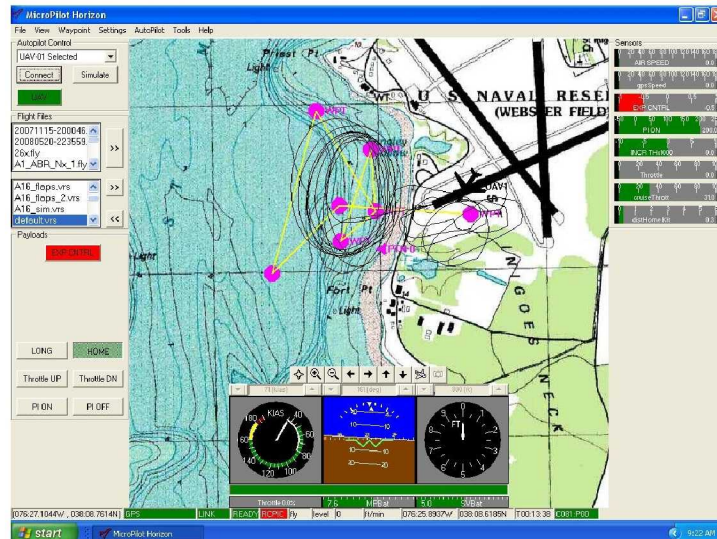


Figure 11. GCS display for Flight Card number 20 , Aug 20, 2008.

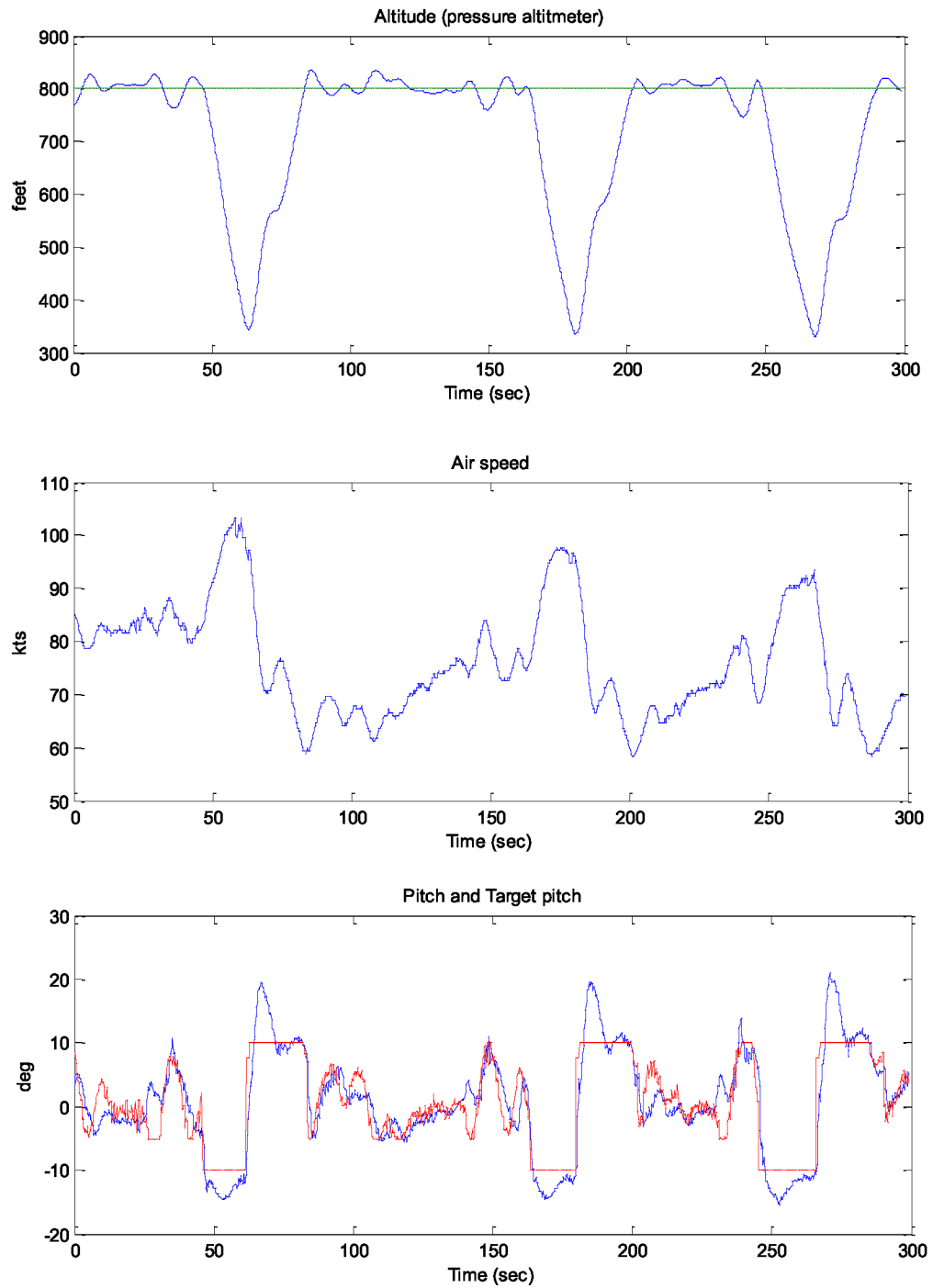


Figure 12. Airspeed, Altitude and Pitch during Flight Card number 13, Aug 21, 2008.



Figure 13. GCS display for Flight Card number 13 , Aug 21, 2008.

CONCLUSION

The major goals of the 2008 flight test campaign were achieved, namely, the demonstrated capability to engage and disengage representative experimental controllers in fully autonomous flight, as well as pilot and ground crew proficiency training covering normal and emergency procedures for both manual and autopiloted operations. Several flight tests were completed where a representative experimental controller was engaged and disengaged while the test platform was under autopiloted control. These flight tests were conducted on both prop-powered and turbine-powered versions of the remotely piloted testbeds. The turbine powered version of the testbed (J-FLiC) provided the capability to test in range of speeds from 50 to 140 knots, and the prop version (FLiC) flew at speeds in the 35 to 65 knot range.

The representative experimental controller was essentially an auto-throttle controller, maintaining desired airspeed in both straight and turning flight at constant altitude. Its primary purpose was to demonstrate that the testbeds support the implementation of a preset, proven control scheme that would provide nominal performance that could be augmented during the test flight with additional control functionality executed while the aircraft was under autopiloted control. The selection of the augmented control was performed by telemetered commands from the

ground control station and it was of utmost importance to be able to revert to the nominal or un-augmented control at any time.

As the flight tests progressed, disturbances to the auto-throttle control were induced by deployment of landing gear and flaps on J-FLiC and similarly by the use of inboard aileron segments on FLiC. Several experimental controller modes were implemented in order to build up confidence in the test technique. The initial tests provided fixed increments to be added to the throttle by inputs from the ground control station to provide compensation for the steady disturbances. This provided some insight into developing reasonable limits to the augmented control. The next step was to provide proportional and integral (PI) corrections to the throttle command to achieve a desired airspeed, in both clean and dirty configurations (gear and flaps). A combination of fixed corrections and PI control served as an intermediate step. By the end of the flight tests, both test-beds had a representative controller that serves as a good baseline for comparison to any proposed advanced concept.

Totals

J-FLiC Training flights	35
J-FLiC Test Flights	25
	===
J-FLiC Total 2008	60
FLiC Training flights	19
FLiC Test flights	7
	===
FLiC Total 2008	26

The test campaign for 2009 is currently underway with initial tests on the new J-FLiC2 air-frame completed in May and June 2009. Plans for 2009 include continued refinements of the nominal autopiloted controls and baseline experimental controller, with extension of the experimental control to multiple-input, multiple-output control (MIMO) utilizing aerodynamic control effectors. Continued development of hardware-in-the-loop benchtop testing will be correlated with flight test results. J-FLiC2 is scheduled to appear in the AUVSI Unmanned Systems Demonstration at Webster Field on Aug 10th, 2009.

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